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Renewable energy research progress in Mexico: A review

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ABSTRACT

Mexico ranks 9th in the world in crude oil reserves, 4th in natural gas reserves in America and it is also highly rich in renewable energy sources (solar, wind, biomasss, hydropower and geothermal). However, the potential of this type of energy has not been fully exploited. Hydropower is the renewable energy source with the highest installed capacity within the country (11,603 MW), while geothermal power capacity (958 MW) makes Mexico to be ranked 4th in the use of this energy worldwide. Wind energy potential is concentrated in five different zones, mainly in the state of Oaxaca, and solar energy has a high potential due to Mexico's ideal location in the so called Solar Belt. Biomass energy has the highest potential (2635 to 3771 PJ/year) and has been the subject of the highest number of research publications in the country during the last 30 years (1982–2012). Universidad Nacional Autonoma de Mexico has led research publications in hydropower, wind, solar and biomass energy and Instituto de Investigaciones Electricas in geothermal energy during this period. According to the General Law for Climate Change the country has set the goal of generating 35% of its energy needs from renewable sources by 2024. This paper presents an overview of the renewable energy options available in Mexico, current status, main positive results to date and future potential. It also analyses barriers hindering improvements and proposes pertinent solutions.

Contents

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1. Introduction

According to the US Energy Information Administration's 2011 report, the current global energy consumption is estimated at 471.8 exajoules (EJ) with fossil fuels supplying 87% [1]. Energy resources have been classified into three categories: fossil fuels, renewable resources and nuclear resources [2]. Fossil fuels have been by far the dominant energy source especially oil, coal and natural gas. The Asia-Pacific region showed the largest consumption of energy (about 35% of the total energy consumption) with China, Japan, India and South Korea as the most important consumers [3]. Due to this level of use, the global reserve/production ratio for oil estimated in 2012 is 54.2 years (Fig. 1) [4]. The reserves of fossil fuels are limited, and their large-scale use is associated with environmental deterioration [5,6]. According to Kalogirou, there are three known major international environmental problems: acid precipitation, stratospheric ozone depletion, and the global climate change [7]. The result has been a rapid growth in the level of greenhouse gas concentration into the atmosphere and an increase in fuel prices [8], which are the main driving forces behind efforts to utilize renewable energy sources [9].

Renewable energy sources (RES) can be defined as sustainable resources available over the long term at a reasonable cost that can be used without negative effects [10,11]. RES include biomass, hydropower, geothermal, solar, wind and marine energies [12]. Renewable energy in 2011 supplied about 19% of the global final energy demand and 9.7% came from modern renewable sources, including hydropower, wind, solar, geothermal and biofuels. Traditional biomass, which is used primarily for cooking and heating in rural areas of developing countries, and could be considered renewable, accounted for approximately 9.3% of the total final energy demand. Hydropower supplied about 3.7% of global final energy demand and hydro capacity is growing steadily. All other modern renewables provided approximately 6.0% of the final energy demand in 2011, and have been experiencing rapid growth in many developed and developing countries (Fig. 2) [13].

The global power generation installed capacity from RES in 2012 exceeded 1470 gigawatts (GW); 67% of this capacity belongs to hydropower stations and 33% of the rest of non-hydro renewable sources. In 2012, the countries with the largest installed capacity from RES were China, United States, Brazil, Canada and Germany. China has the largest installed capacity for hydropower and wind energy, Germany for solar energy and United States for biomass and geothermal energy [13]. In the European Union, the RES installed capacity reached 325 GW, with a main contribution from hydropower (147 GW), wind (94 GW), solar (52 GW) and biomass (31 GW) [14]. The RES sector is expected to continue growing in the future, especially in solar and wind equipment production. Technologies for the RES will also show a decrease in production costs as a result of accelerated technology developments, an increase in green equipment manufacturing and the degree of investment worldwide (Fig. 3) [13].

The use of biomass as a primary source of bioenergy has been decreasing in Mexico since 1965, when it constituted 15.3% of the total primary energy supply. This share represented only 5.3% in 2005. Nowadays, the use of hydrocarbon fuels has been steadily increasing and accounted for 88.7% of the gross primary energy supply [15]. There are several reasons to increase the use of RES in Mexico. The increasing reliance on fossil fuels is really problematic. In 2007, the national proven reserves of hydrocarbon were considered to be enough to support the annual oil and gas production only for 9.6 and 8.9 years respectively [16]. The annual average growth rate of Mexico's energy related non-biogenic CO_2 emissions is 4.3%, one of the highest in the world [17]. On the other hand, RES have the potential to become a fundamental piece in a sustainable energy system, contributing not only to country's energy diversification strategy, but also to the appropriation of emerging energy technologies. This sustainable energy model might result from the combined use of different RES as has been proposed by other authors [18–21], by applying innovative solutions, such as the GSHP and aluminium-containing SAH systems [22–24], that have shown attractive savings compared to conventional fuels (fuel oil, petrol gas, coal and natural gas). This can contribute to the reduction of greenhouse gas emissions, the generation of new jobs in rural areas and the improvement of

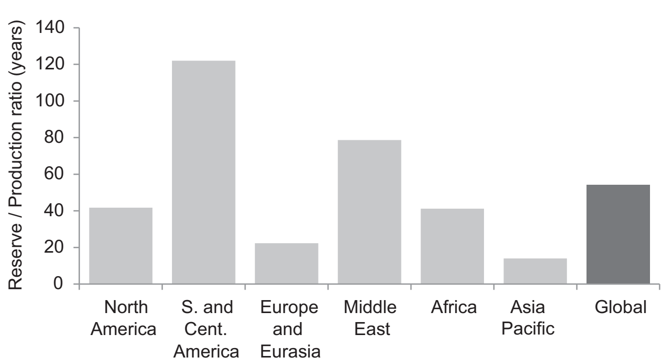


Fig. 1. The oil reserve/production ratio for proven resources worldwide [4].

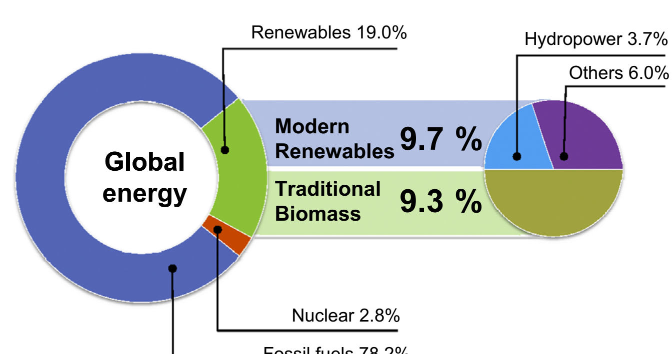


Fig. 2. Renewable energy share of global final energy demand, 2010 [13].

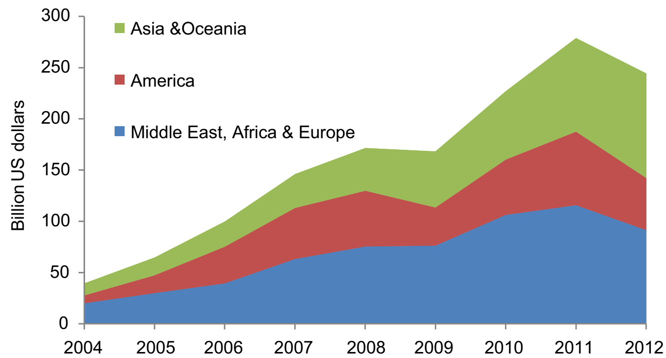


Fig. 3. Global new investment in renewable energy by region, 2004–2012 [13].

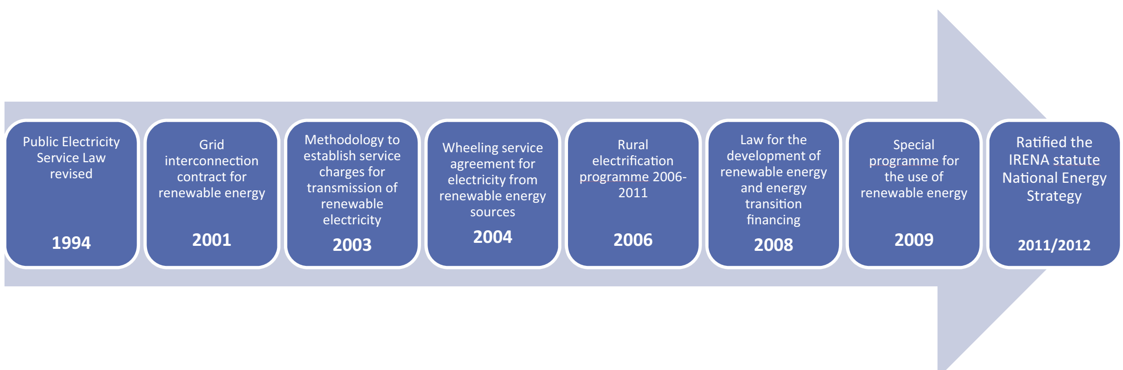


Fig. 4. Policies time line about power generation from RES progress [25].

income distribution. Also, the resulting independence from current energy import, mainly gasoline and diesel and soon jet fuel, is important for economic and national security reasons. Mexico has already been taking initiatives in policies to promote renewable energies since the Rio Conference of 1992 (Fig. 4) [25]. In this context, this paper addresses the state of current renewable energy sources in Mexico at research and practical levels and explains barriers and presents alternatives.

2. Geographical, economical and energy status of Mexico

2.1. Geographical and climate conditions

Mexico's total area covers 1,972,550 square kilometers, including islands in the Pacific Ocean, Gulf of Mexico, Caribbean Sea, and Gulf of California. The northern border with the United States is 3326 km. On the south, Mexico shares an 871-kilometer border with Guatemala and a 251-kilometer border with Belize. Mexico has a coastline of 10,143 km, 7338 km face the Pacific Ocean and the Gulf of California, and the remaining 2805 km front the Gulf of Mexico and the Caribbean Sea [26]. The landmass of Mexico dramatically narrows in a southeasterly direction from the United States border and then abruptly curves northward before ending in the 500-kilometer-long Yucatan Peninsula. Two prominent mountain ranges, the Sierra Madre Occidental and the Sierra Madre Oriental, define northern Mexico. According to Merrill and Mirró, Mexico has nearly 150 rivers, two-thirds emptying into the Pacific Ocean and the remainder into the Gulf of Mexico or the Caribbean Sea. Despite its apparent abundance of water, water volume is unevenly distributed throughout the country. Northern and central Mexico cover 47 percent of the national area and almost 60 percent of Mexico's population, but have less than 10 percent of country's water resources [27]. The Mexican National Water Commission CONAGUA generated a map to illustrate the distribution of natural water availability, population and gross domestic product (GDP), dividing the country in two areas, one of them is southeast and the second includes north, center and northwest. The map shows that the southeast region has 69% of the fresh water available, 23% of the population and produce only 13% of the GDP (Fig. 5) [28].

The variety of lowlands and highlands that comprise the complex geography of Mexico has a major impact on its climate. The Tropic of Cancer effectively divides the country into dry, very dry, warm and temperate weather zones. Table 1 [29] describes the area comprised for each one of these climatic regions, annual precipitations and temperatures. Temperatures vary between 10 and 26 °C. According to CONAGUA, August has 140 mm of average rainfall, being the wettest month, July and September show 135 mm, while March is the driest month with 12 mm followed by February and April with 16 mm (Fig. 6) [30].

2.2. Economic and energy status in Mexico

According to the National Institute of Statistics, Geography and Informatics (INEGI) [31], the country had a population of 112.3 million in 2010 and it was characterized by an annual population growth rate of 0.9%. About 77.8% of this population lived in urban areas [32]. A summary of the demographic and economic information on Mexico is given in Table 2.

Energy production is one of the most important economic activities in Mexico contributing to 3% of the GDP. Oil commercialization represents 8% of total exports, and oil-related taxes account for 37% of the federal budget, where about 56.5% of all public investment is directed towards energy projects. Public companies in the oil and energy sectors employ approximately 250,000 workers [33]. Mexico ranks ninth in the world in crude oil

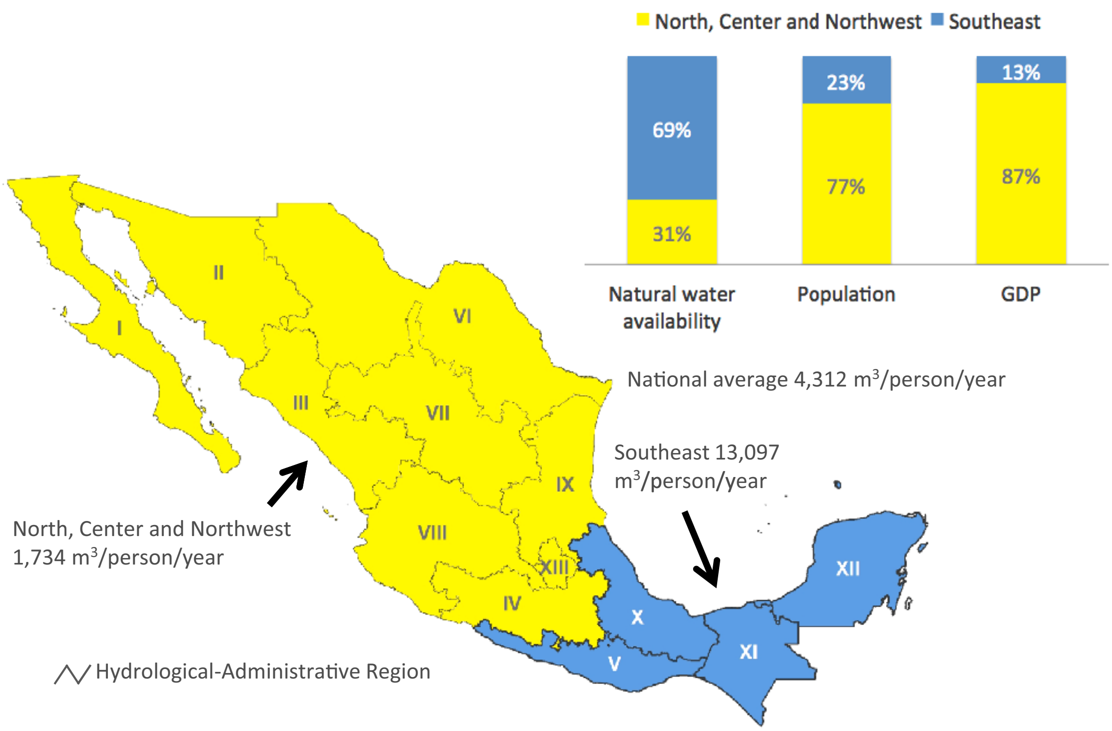


Fig. 5. Map of the regional contrast between development and water availability [28].

Table 1
Weather conditions in Mexico [29].

Weather		Temperature (°C)	Annual precipitation (mm)	Area of the country (%)
Dry		18–22	300–600	28.3
Very dry		18–26	100–300	20.8
Warm	Wet	22–26	2000–4000	4.7
	Humid	22–26	1000–2000	23
Temperate	Wet	18–22	2000–4000	2.7
	Humid	10–18	600–1000	20.5

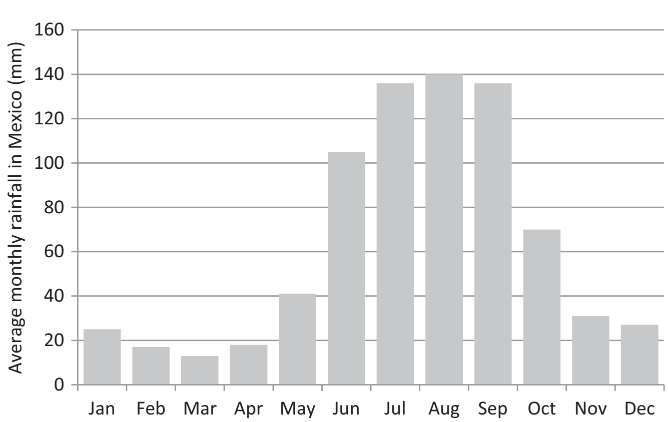


Fig. 6. Average monthly rainfall in Mexico [30].

reserves and fourth in natural gas reserves in America, just after the United States, Venezuela and Canada. The Mexican Petroleum Company (PEMEX) is the seventh largest petroleum company worldwide by its crude oil output and one of the most profitable before taxes. In terms of electricity generation, Mexico ranks 16th worldwide, and the Federal Electricity Commission (CFE) is the 6th largest power company in the world [34]. Electricity coverage reaches 95% of the national population, one of the highest coverage rates in Latin America [35].

Table 2
Demographic and economic indicators of Mexico [32].

Parameter	Year	Value
Population mid-year(millions)	2009	109.6
Gross domestic product(GDP) (millions USD)[a]	2009	872088.0
GDP per capita(USD)	2009	7956.3
Energy production, primary($\times 10^3$ Mtoe[b])	2009	210.9
Population growth rate(%)	2010–2015	0.9
Urban population(%)	2010	77.8
Forested area(%)	2008	33.5
CO_2 emission estimates($\times 10^3$ tonnes)	2007	471.1
Energy consumption per capita(kgOE)[c]	2008	1437.0

[a] USD – United States Dollars.
[b] Mtoe – Mega tones oil equivalent.
[c] kgOE – kilograms oil equivalent.

Mexico is one of the largest oil producers in the world; although oil production in the country has begun to decrease, as the Cantarell oil field production declines. This oil complex located 80 km offshore in the Bay of Campeche is by far the largest oil field in Mexico. As mentioned before, the petroleum sector is a crucial component of Mexico's economy, which generated approximately 16% of the export earnings in 2011, according to Mexico's central bank. However, this percentage has declined over time, consequently, energy imports have increased since the last decade [36].

In 2008, the share of imports from total supply represented 15% for natural gas, 40% for gasoline and 15% of diesel. Fig. 7 shows the actual imports (from 2000 to 2011) and projected imports (from 2012 to 2026) of different fuels. Gasoline represents the highest imports from these ranging from 135.8 thousands of barrels per day (kbpd) to an expected import of 666.8 kbpd in 2026, mainly due to the gradual increase of demand. Regarding diesel, imports

go from 42 kbpd to 69.8 kbpd with an expected decrease until 2015. Thereafter, Mexico is expected to become a diesel exporter until 2021 due to increase of infrastructure needed to produce this fuel, but the imports will start again as the production of diesel remain stagnant. Finally, Mexico has not being jet fuel self-sufficient since 2011. From 2012 to 2026 imports will increase gradually mainly because a high national and international demand in this sector [37]. Fuel imports reached 29 billion USD (7.7% of total imports) by 2009 [25]. Mexico's total energy consumption relies mostly on oil and natural gas, where the latter replaces increasingly the oil as fuel in power generation [36]. The remaining energy sources contribute slightly to Mexico's overall energy mix. Besides oil, Mexico is exporting electricity, for example in 2006 it exported 1299 GWh; 1088 GWh to the USA, 204 GWh to Belize and 2 GWh to Guatemala. By 2010, electricity exports increased to 1320 GWh (Table 3) [38].

According to the national energy databases [15], Mexico produced 219.5 million tons of oil equivalent energy during 2011. An estimated 88.69% came from fossil fuels, 6.98% from renewable sources, 3.17% from charcoal and the remaining 1.16% from nuclear sources (Fig. 8).

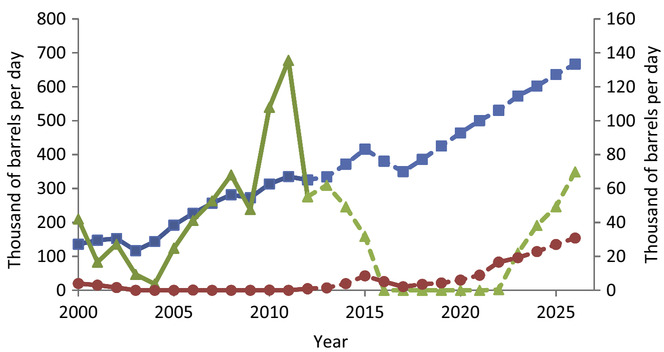


Fig. 7. Thousands of barrels per day of imported of gasoline (squares, left axis), diesel (triangles, right axis) and jet fuel (circles, right axis). Actual imports (solid line), projected imports (dashed line) [37].

Table 3
Mexico's energy exportation [38].

Type	Quantity	Unit	Exportation world ranking
Electricity[b]	1320	GWh	50
Crude oil[a]	1.299 million	bbl/day	13
Refined petroleum products[a]	199,000	bbl/day	33
Natural gas[c]	13 million	cu m	49

[a] Estimated in 2009.
[b] Estimated in 2010.
[c] Estimated in 2011.

3. Energy policy in Mexico

Similar to other world regions, Mexico experienced important reforms in the energy sector in power, gas and oil segments during the 1990s. These reforms were driven by ideological belief, budgetary pressures and a desire to raise efficiency and attract private capital [39]. Specifically in electricity, there is a state-integrated system with private investments only opened for power generation [40,41]. The participation of private firms in the natural gas industry downstream markets was allowed in 1997, but upstream belongs to the public state-owned company, PEMEX. This market has been opened by regions to only one company, inhibiting competition [36]. However, the Congress of the Union recently approved the Energy Reform where articles 25, 26 and 27 of the Constitution were modified to allow the participation of private firms in the energy sector in order to share technology and experience. This law regulates, among others, the participation in the exploration and extraction of oil and natural gas in the following forms: (i) in cash for service contracts, (ii) with a percentage of income for contracts of shared utility or (iii) a percentage of the production obtained for the shared production contracts; (iv) with the transfer of hydrocarbons once they have been extracted from the subsoil for license agreements or (v) any combination of the above. Private investment is also allowed in the power generation. The participation of individuals along with the CFE in the power generation might be more flexible. Once oil revenues ensure a GDP of 4.7% based on the year 2013, these revenues will be allocated in a long term account. From this fund, 10% will be used to finance projects in science, technology and renewable energies, 10% for the universal pension system, 10% in scholarships for development of human capital in universities and postgraduate and 30% in oil projects by Energy Ministry and development of national infrastructure [42].

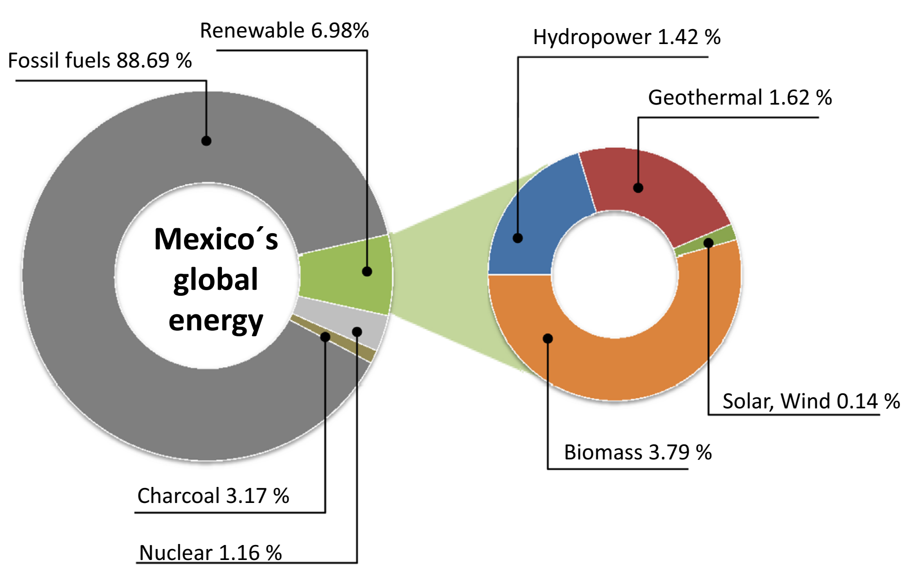


Fig. 8. Mexico's energy global production, 2011 [15].

Mexico has a legal framework for the energy sector (from the Constitution to the Energy Laws and Programmes) which demonstrates the role of the Mexican State and the particularities of its institutions and its functions [43]. A report produced by GTZ (Germany) in collaboration with the Energy Ministry in Mexico (SENER) reported that renewable energies have been included in the Mexican public policies for decades but they were given an important role in the National Strategic Plan for Development (NDP) during the last presidential period (2006–2012) [44]. In this Plan, energy is related to human development in agreement with the United Nations Development Programme [45].

According to Alatorre the NDP included three particular objectives related to renewable energy [46]:

1) to balance the portfolio of primary energy sources to renewable energies in the generation capacity from 23 to 26% as follows: large hydroelectric projects (above 70 MW) 17%; small hydroelectric projects 3% and other renewables 6%.
2) to promote the use of renewable energy sources and biofuels in economically, environmentally and socially responsible forms.
3) to mitigate the increase of greenhouse gas emissions reducing emissions from 14 $MtCO_2eq$ in 2006 to 28 $MtCO_2eq$ in 2012, 261 $MtCO_2eq$ in 2020 and 523 $MtCO_2eq$ in 2030.

Three main legal instruments are expected to promote renewable energy in Mexico. One is the recent Energy Reform approved by the Congress of the Union. The second instrument is the General Law for Climate Change adopted in May 2012 which sets the goal of 35% of energy generated in the country should come from renewable sources by 2024 [47]. Although the degree of contribution for each technology has not been defined, RES installed capacity is planned to increase to 1, 2, 12 and 1.5 GW for biomass, geothermal wind and solar energy respectively by 2020 [48]. Finally, the Law for the Use of Renewable Energy and Finance of the Energy Transition, recently modified and approved [49]. This Law establishes, among other issues, the legal aspects and conditions for the use of renewable energy and clean technologies as well as reducing the use and dependency of fossil fuels. For instance, use of 2% of ethanol in gasoline in Guadalajara, Monterrey and Mexico City was introduced by the end of 2012 [50]. Additionally, the Law creates a Fund for the transition to clean and renewable energy and technologies. The Fund will create a Technical Committee for the administration, and the assignment and distribution of resources in order to promote the goals of the Strategy. The Committee might also decide on the use of the Fund for channeling credit and other financing support to foster the energy transition, energy saving, clean technologies and renewable energy. These three legal instruments are expected to create a better framework to support renewable energy in general and also a future green economy in Mexico.

4. Renewable energy scientific progress in Mexico

A literature review on the status and progress of research in the main renewable energy sources worldwide and in Mexico during the last 30 years (1982–2012) was conducted, using the methodology previously described elsewhere [51]. This study used the number of web publications in the Scopus database as a reference, as has been done for other studies from different areas of knowledge such as chemical engineering, environmental sciences, separation and purification technologies [52–61]. Briefly, the methodology consisted in an extensive literature search (article and conference papers). The keywords used for each renewable energy were as follows: for solar: solar energy, solar thermal energy, solar power and photovoltaic; for wind energy: wind energy, wind power and wind farm; for biomass: biomass, bioenergy, biogas and biofuel; for geothermal: geothermal energy, geothermal electricity, geothermal heating; and for hydropower: hydropower and hydroelectric.

Fig. 9 shows the percentages of all scientific publications in the Scopus database related to renewable energies during the period 1982 to 2012 in Mexico. It is noted that almost three quarters of the research publications (70.1%) have been focused on the use of biomass as renewable energy, followed by solar energy (19.2%), geothermal (4.5%), wind (4.0%) and finally hydropower (2.2%). These data highlight the relatively low attention (2.2%) on hydropower research, although it is one of the renewable energy sources that produces more power in Mexico (besides geothermal and biomass sources). A possible explanation for this could be that this technology is regarded as the most mature (the majority of the large scale hydro projects were built mainly in the 70s and 80s) of all considered RES [62]. It can be pointed out that some of these technologies have not been researched since the beginning of this period unlike biomass energy. Geothermal and hydropower did not show any reported document until 1985 and 1988 respectively. The newest research in Mexico focuses on wind energy which started in 1994.

Taking into account the evolution of this research publications (Fig. 10), hydropower and geothermal have been stable over the last 30 years, whereas biomass, solar and wind power are evolving following an exponential trend through the time. The investigation into these three renewable energies has accelerated since 1994, when they began to be significant resources. However, wind energy is a relatively new technology in Mexico and it showed a delay in exponential trend until 2008. In order to compare the scientific production carried out in Mexico and worldwide, the same methodology mentioned above was performed using a country filter (for Mexico) or without country filters. The findings are presented in the following sections.

4.1. RES in Mexico in the world ranking

The main institutions in Mexico that have contributed the most to research and scientific progress in various fields of RESs are listed in Tables 4–8. This paper considers the ten institutions that have provided the most scientific production in the last 30 years

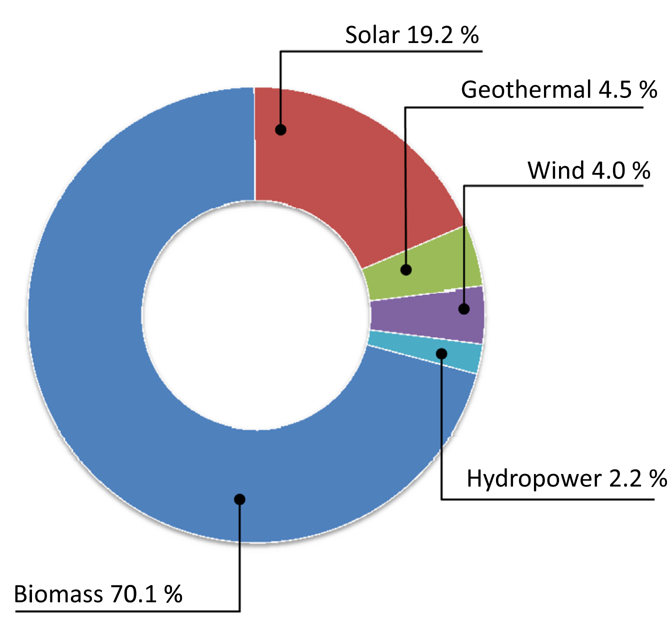


Fig. 9. Research effort of renewable energy sources in Mexico from 1982–2012.

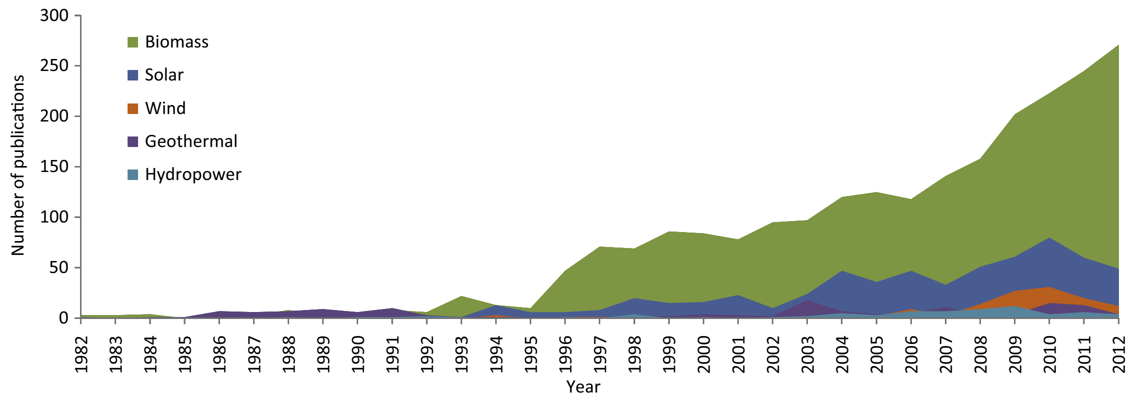


Fig. 10. Evolution of scientific research on renewable energy sources (1982–2012).

Table 4
Leading mexican institutions by number of publications on solar energy in the period 1982–2012.

Institution	Solar (%)	Type
Universidad Nacional Autónoma de México	25.10	Public
Centro de Investigacion y de Estudios Avanzados	9.25	Public
Instituto Politécnico Nacional	5.41	Public
Instituto de Investigaciones Electricas	2.17	Public
Universidad Autónoma del Estado de Morelos	2.17	Public
Centro Nacional de Investigación y Desarrollo Tecnológico, Mexico	1.97	Public
Centro de Investigacion en Materiales Avanzados	1.77	Public
Universidad Autónoma de Yucatán	1.48	Public
Universidad Autónoma Metropolitana – Iztapalapa	1.48	Public
Benemérita Universidad Autónoma de Puebla	1.38	Public

Table 5
Leading mexican institutions by number of publications on wind energy in the period 1982–2012.

Institution	Wind (%)	Type
Universidad Nacional Autónoma de México	11.88	Public
Universidad Michoacana de San Nicolás de Hidalgo	6.90	Public
Instituto Politécnico Nacional	5.75	Public
Instituto Tecnologico de Morelia	4.21	Public
Tecnológico de Monterrey	3.07	Private
Universidad Autónoma de Yucatán	2.68	Public
Instituto de Investigaciones Electricas	2.68	Public
Centro de Investigacion y de Estudios Avanzados	1.92	Public
CINVESTAV Unidad Guadalajara	1.15	Public
Instituto Tecnológico de Ciudad Madero	1.15	Public

and the participation of each one in the development of the different RES is described below.

4.1.1. Solar

Mexico occupies 27th place with a contribution of 0.71% in solar energy research worldwide, whereas USA (21.8%), China (11.5%) and Japan (6.6%) are the principal sources of information in this field. As shown in Table 4 the institution that has the largest number of publications on this technology in the last 30 years in Mexico is Universidad Nacional Autonoma de Mexico (25.10%), followed by Centro de Investigacion y Estudios Avanzados (9.25%) and third the Instituto Politecnico Nacional (5.41%).

4.1.2. Wind

Regarding wind technology, Mexico occupies 34th place with a contribution of 0.43%, and the countries that have the most publications are China (17.8%), USA (14.8%) and United Kingdom (7.1%). Universidad Nacional Autonoma de Mexico (11.88%) is the Mexican institution with the highest research publications, followed by Universidad Michoacana de San Nicolas de Hidalgo (6.90%) and, third the Instituto Politecnico Nacional (5.75%) (Table 5).

Table 6
Leading mexican institutions by number of publications on biomass energy in the period 1982–2012.

Institution	Biomass (%)	Type
Universidad Nacional Autónoma de México	12.07	Public
Colegio de Postgraduados	4.06	Public
Instituto Politécnico Nacional	3.92	Public
Centro de Investigacion y de Estudios Avanzados	3.78	Public
Universidad Autónoma Metropolitana – Iztapalapa	3.18	Public
Centro de Investigaciones Biologicas Del Noroeste	2.90	Private
Centro Internacional de Mejoramiento de Maiz y Trigo	2.87	Public
Centro de Investigacion Cientifica y de Educacion Superior de Ensenada	2.84	Public
Centro Interdisciplinario de Ciencias Marinas	2.67	Public
El Colegio de la Frontera Sur	2.07	Public

4.1.3. Biomass

Mexico occupies the 20th place with a contribution of 1.1% in biomass research, whereas USA (21.4%), followed by China (8.4%) and Germany (5.1%) are the countries that have contributed the most in this field. Table 6 shows that research of biomass energy during the last 30 years has been led by Universidad Nacional Autonoma de Mexico (12.07%), Colegio de Postgraduados (4.06%) and Instituto Politecnico Nacional (3.92%).

Table 7
Leading mexican institutions by number of publications on geothermal energy in the period 1982–2012.

Institution	Geothermal (%)	Type
Instituto de Investigaciones Electricas	40.10	Private
Universidad Nacional Autónoma de México	12.38	Public
Comisión Federal de Electricidad	7.43	Public
Universidad Autónoma de Baja California	1.98	Public
Centro Nacional de Investigación y Desarrollo Tecnológico	1.98	Public
Instituto Nacional de Investigaciones Nucleares	1.98	Public
Universidad Autónoma Metropolitana – Iztapalapa	1.98	Public
Universidad Michoacana de San Nicolás de Hidalgo	1.98	Public
Universidad Autónoma del Estado de Morelos	1.49	Public
Gerencia de Proyectos Geotermoelectricos	1.49	Public

Table 8
Leading mexican institutions by number of publications on hydropower in the period 1982–2012.

Institution	Hydropower (%)	Type
Universidad Nacional Autónoma de México	13.39	Public
Comisión Federal de Electricidad	9.82	Public
Instituto de Investigaciones Electricas	7.14	Public
Instituto Tecnológico de Puebla	3.57	Public
Universidad de Guadalajara	1.79	Public
Centro de Investigacion y de Estudios Avanzados	1.79	Public
Instituto Mexicano de Tecnologia del Agua	1.79	Public
Universidad Autónoma de Tamaulipas	1.79	Public
Universidad Autónoma del Estado de Morelos	1.79	Public
Instituto Nacional de Astrofisica Optica y Electronica	1.79	Public

4.1.4. Geothermal

Geothermal energy has been studied mainly by USA (26.7%), Germany (7.2%) and China (7.1%). Mexico occupies the 9th place with a contribution of 3.0%. The institutions that have the highest number of research publications were Instituto de Investigaciones Electricas (40.10%), followed by Universidad Nacional Autonoma de Mexico (12.38%) and Comision Federal de Electricidad (7.43%) (Table 7).

4.1.5. Hydropower

This RES has been researched specially by China (23.5%), USA (17.2%) and Canada (5.9%), whereas Mexico contributes with 0.4% of research publications and occupies the 29th place. In Mexico (Table 8), this technology has been studied mainly by Universidad Nacional Autonoma de Mexico (13.39%), Comision Federal de Electricidad (9.82%) and Instituto de Investigaciones Electricas (7.14%).

4.2. Outlook of research publications of RES in Mexico

RES research worldwide is highly concentrated in a few countries (12–14 depending upon the energy) accounting for 70% to 80% of the total scientific production [51]. The present study indicates that renewable energy research has been led during the last 30 years by the USA (solar energy, biomass energy and geothermal energy) and China (wind energy and hydropower). Regarding Mexico, the country showed the lowest contribution in hydropower and wind energy. The possible explanation for this low percentage is that research of these technologies started much later than the others, 1988 and 1994 respectively. Geothermal energy had the highest contribution among global RES, where Mexico exhibited a significant development on geothermal generation and is one of the RES that contributes the most to the renewable sector (Fig. 8). Notably, the Universidad Nacional Autonoma de Mexico is the institution that has contributed the most in research publications in 4 out of 5 renewable energy sources. In the case of geothermal energy, the Instituto de Investigaciones Electricas has mainly led this research. However, these research publications in Mexico barely surpassed 1% of the worldwide research (except geothermal energy), despite the increase in the number of publications about renewable energy sources in the Mexican power sector it is regarded to be low [63].

5. Renewable energy use and potential in Mexico.

5.1. RES in Mexico

Power generation in Mexico is dominated by thermoelectrics (using fossil fuels) and is followed by renewable energy sources. According to the national energy databases [15], Mexico produced 260,525 GWh during 2012. On the other hand, national consumption was 206,480 GWh where the industrial sector was characterized by its high consumption and extensive patterns of demand. This sector consumed 58.8%, the residential sector 25.2% and services and agricultural sector 16%. Power generation from RES increased from 26 terawatts (TW) in 2003 to 39 TW in 2012, however RES contribution to overall power generation has remained stagnant with an average of 16% (Fig. 11) [64]. By the first two months of 2012, power generation installed capacity from RES in Mexico was 14,357 MW of which 87.3% was owned by the public sector and 12.7% by the private sector. From this capacity 80.8% belongs to hydropower, 8.5% to wind energy, 6.7% to geothermal energy, 3.8% to biomass energy and 0.2% to solar energy. RES projects are present in 90% of all federal states, and two hundred and four power stations are functional or under construction with a total installed capacity of 5505 MW. The 75% of this capacity is concentrated in the states of Oaxaca, Baja California, Veracruz and Nuevo Leon. Oaxaca and Veracruz have the highest number of wind and biomass projects respectively (Table 9). By law, only hydroelectric projects with an installed capacity up to 30 MW are allowed to be owned by the private sector [65].

5.2. Solar

Mexico is one of the top five most attractive countries in the world to invest in photovoltaic (PV) solar power projects, only behind China and Singapore. The potential of solar energy in Mexico is one of the highest in the world [34]. This is because the country is located in the so called "solar belt" with radiation exceeding 5 KWh per square

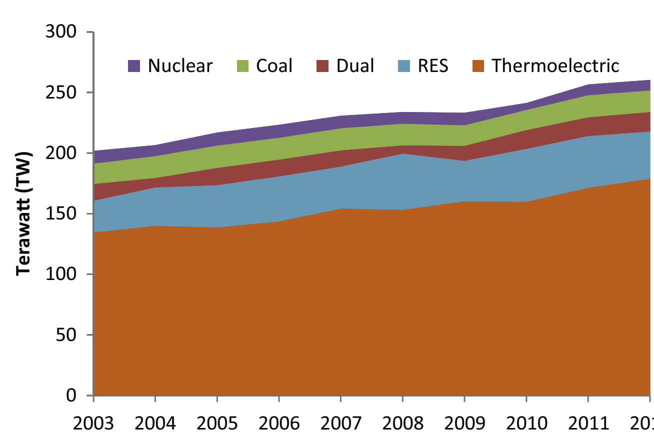


Fig. 11. Cumulative contribution to power generation by source [64].

meter per day [66]. Furthermore, Mexico has the largest PV module manufacturing base in Latin America [67]. Within Mexico, the solar energy potential is highly accumulated in the north-western part of the country. Fig. 12 shows the annual global solar radiation in Mexico that goes from 5.6 to 6.1 KWh/m^2-day [68]. In comparison, despite the recent significant growth in solar energy production in the European Union, the potential of solar energy in Europe is far lower.

5.2.1. Solar PV power

There are 33 MW of solar PV installed capacity so far in Mexico in operation, but several projects under construction to reach an additional installed capacity of 39.1 MW (Table 10). By the end of 2011, the Spanish company Siliken announced a PV investment project called “La Manzana del Sol” (Sun′s apple) in the state of Durango. The project will have an installed capacity of 100 MW during the first stage and 400 MW in the next five years. Mexico is the main supplier of PV modules in Latin America and has an annual production capacity above 276 MW (just above Brazil, Chile and Argentina). Some of the leading PV power developers are Abengoa, Abener, Del Sol systems, Microm, Iberdrola and Siliken [46].

Table 9
Renewable power stations in 2012 (MW) [67].

State	Source					
	Biomass	Wind	Geothermal	Hydro ($x \leq 30$ MW)	Solar	Total
Oaxaca	33	2422		21		2476
Baja California		102	720	24	5	851
Veracruz	270	40		125		435
Nuevo Leon	28	274				302
San Luis Potosi	41	200		20		261
Michoacan	15		188	28		231
Tamaulipas	13	215				228
Jalisco	61			72	30	163
Puebla	15		40	39		94
Chiapas	22	29		28		79
Otros	144	2	10	213	17	386
Total	642	3284	958	570	52	5506

5.2.2. Concentrated solar power and water heaters

The “171 CC Agua Prieta II” project started operations in Sonora. This development has two stations: one combined cycle of 477 MW and one solar with parabolic channels with a capacity of 14 MW. According to the latest National Energy Balance report, water heater installations increased by 19% over the previous year, reaching 1,665,502 m^2 in 2010. This technology is mainly used in Mexico to heat water for pools, hotels, sports, clubs, homes, hospitals and industries [46,67].

5.3. Wind

The installed capacity of wind power farms in operation reached about 1215 MW (Table 11). Only 7% is operated by the Federal Commission of Electricity (CFE), and the rest is operated through licensees under self-sufficiency, small producers and dependent producer contracts. The self-supply scheme allows companies to generate electricity for self-consumption by establishing a body/entity whose main purpose is to satisfy all the energy requirements of its partners [69].

The main wind power generation system is in the south-east of Mexico (La Venta-Oaxaca). This system is connected to the national interconnected grid system with a power capacity of 84.6 MW, and a capacity factor of nearly 40% during 2008 (Table 11). It is planned to add 591 MW through private generators [63]. Mexico has a wind energy potential of 71,000 MW [70], although only 1.7% of this potential is currently in use. As shown in Fig. 13 there are different zones with wind energy potential [68,71]:

A) Isthmus of Tehuantepec (Oaxaca): it is the location of the majority of Mexico′s wind parks. They have a capacity of 1174 MW in operation and there are also seven projects under construction, with a total estimated capacity of 1248 MW. It is

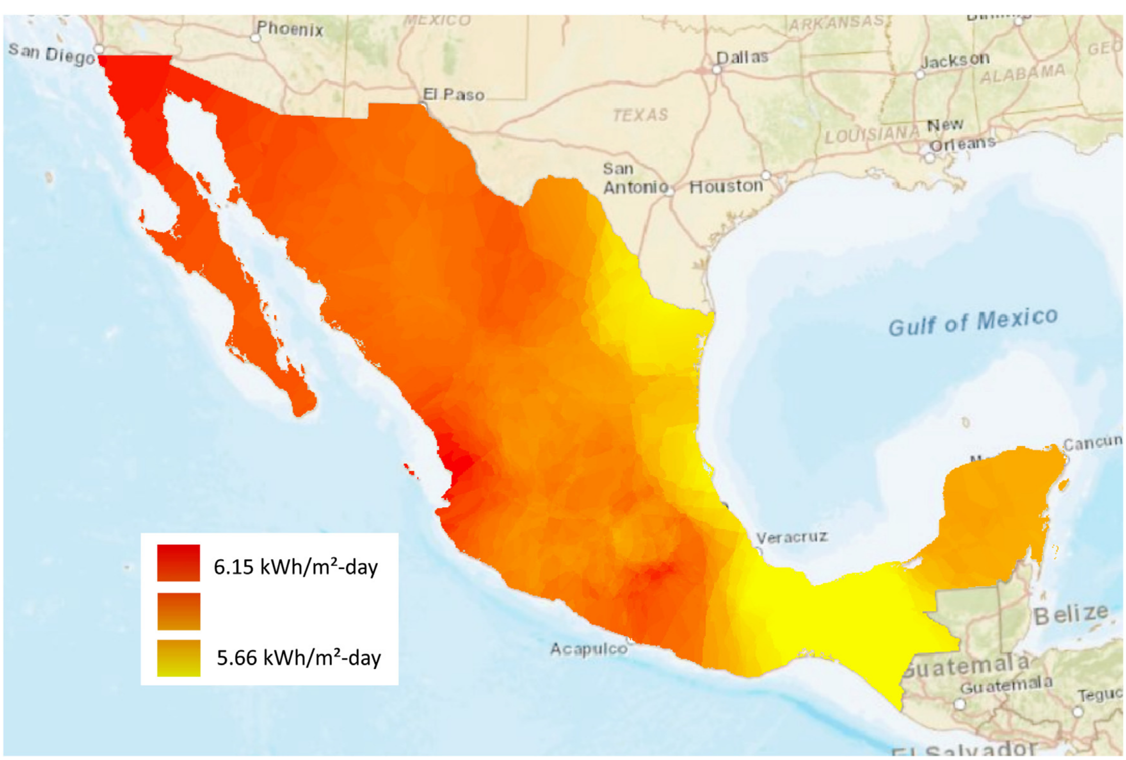


Fig. 12. Atlas of solar source potential [68].

Table 10
Solar PV stations 2012 [67].

Station/License	Status	Installed capacity (MW)	Location	Owned by
Small and medium scale contracts	In operation	32.0	–	Private
Private PV central, Santa Rosalia	In operation	1.0	Baja Califronia Sur	Public
PV project, Durango	To begin operations	0.5	Durango	Private
PV project (self supply)	Under construction	3.8	Agusacalientes	Private
PV project (smal producer)	Under construction	29.8	Jalisco	Private
Pilor PV centrral, Cerro Prieto	Under construction	5.0	Baja Califronia Sur	Public
Total		72.1		

Table 11
Wind power stations 2012 [67].

Station/License	Status	Installed capacity (MW)	Location	Owned by
La Venta	In operation	84.6	Oaxaca	Public
Guerrero Negro	In operation	0.6	Baja California Sur	Public
Wind turbine, Cancun	In operation	1.5	Quintana Roo	Public
–	In operation	1128.0	baja California, Chiapas and Oaxaca	Private
–	Under construction and about to begin	2069.0	Baja California, Nuevo Leon, Oaxaca, San Luis Potosi, Tamaulipas and Veracruz	Private
Total		3283.7		

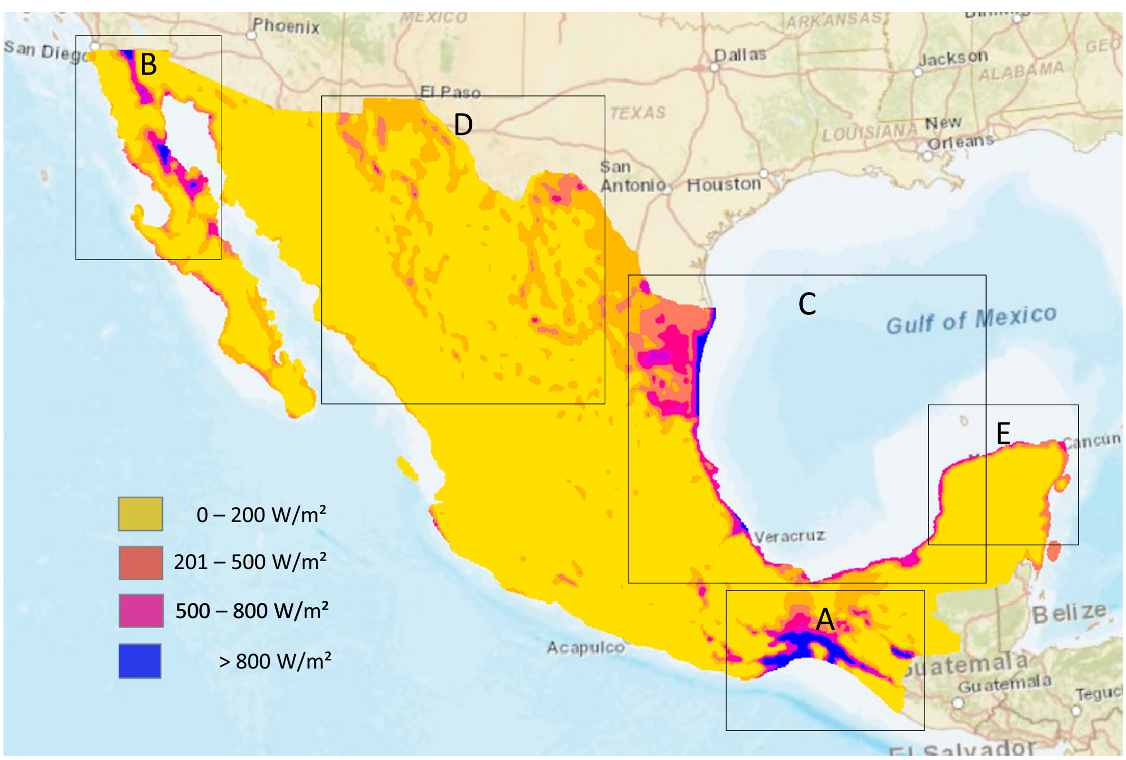


Fig. 13. Atlas of wind source potential. Squares indicate zones with high potential; (A) Isthmus of Tehuantepec, (B) State of Baja, (C) The coast Gulf of Mexico, (D) Northern and central region and (E) Coast of Yucatan [68].

estimated that this region has a potential of more than 40,000 MW due to the excellent wind conditions.

B) The State of Baja California has a wind potential that exceeds 5000 MW. There are currently three projects under construction with a total installed capacity of 102 MW in the Rumorosa region. Unfortunately, the project development schedule in this area has been delayed by legal uncertainty in land lease contracts between private developers and communal land owners in the area.

C) The coast of the Gulf of Mexico: It is formed by the bay of Campeche and the states of Tamaulipas and Veracruz where a 161 MW project is planned to be built in.

D) The Northern and Central Region comprised by the states of Nuevo León, Coahuila, Chihuahua and Sonora have lower capacity factors in the range of 20–30%. Nuevo Leon has installed 274 MW for power generation and San Luis Potosi has a wind power station under construction with an expected capacity of 200 MW.

Table 12
Hydropower stations by 2012 [67].

Station	Status	Installed capacity (MW)	Location	Owned by
Hydro ≤ 30 MW	In operation	287.0	Chiapas, Chihuahua, State of Mexico, Guerrero, Hidalgo, Jalisco, Michoacan, Nayarit, Oaxaca, Puebla, San Luis Potosi, Sinaloa, Sonora and Veracruz	Public
Hydro ≤ 30 MW	Inactive	11.0	State of Mexico, Puebla, Queretaro and Veracruz	Public
Hydro ≤ 30 MW	In operation	11169.0	Chiapas, Coahuila, Guerrero, Hidalgo, Jalisco, Michoacan, Morelos, Nayarit, Oaxaca, Puebla, Sinaloa, Sonora, Tamaulipas and Veracruz	Public
Hydro ≤ 30 MW	In operation	147.0	Durango, Guanajuato, Guerrero, Jalisco, Puebla and Veracruz	Private
Hydro ≤ 30 MW	Under construction	136.0	Baja California, Guerrero, Jalisco, Nayarit, Oaxaca and Veracruz	Private
Hydro ≤ 30 MW	Inactive	25.0	Jalisco, Oaxaca and Puebla	Private
Total		11775.0		

Table 13
Geothermal power stations owned by CFE [67].

Station	Status	Installed capacity (MW)	Location
Cerro Prieto (I, II, III, IV)	In operation	720.0	Baja California
Los Azufres	In operation	188.0	Michoacan
Los Humeros	In operation	40.0	Puebla
Tres Virgenes	In operation	10.0	Baja California Sur.
Cerritos Colorados	Under construction	75.0	Jalisco
Total		1033.0	

E) The coast of the Yucatan Peninsula: it has wind potential because of its excellent wind flows on the coast of Quintana Roo and the island of Cozumel.

5.4. Hydropower

The hydropower generation capacity in Mexico is managed by both private and public sectors. In 2012, CFE reported 11,603 MW of installed capacity among its 72 stations in operation (Table 12); this included hydroelectric stations with 30 MW or below. The private sector has 28 stations located in nine states with a total installed capacity of 308 MW. Although the full potential for this form of energy generation has not been completely estimated, the National Commission for the Efficient Use of Energy (CONAE) has already identified over 100 possible sites for its exploitation. For example, in the states of Veracruz and Puebla, it is estimated that there is a potential for the generation of 3570 GWh/year equivalent to an average installed capacity of 400 MW [67].

5.5. Geothermal

Mexico has a significant development on geothermal generation and is ranked fourth in geothermal power generation worldwide [72]. The state of Baja California has the largest share in this technology. Present installed geothermal-electric capacity in Mexico is 958 MW (Table 13), although the effective or running capacity is 883 MW because two old 37.5-MW power units in Cerro Prieto were decommissioned in 2011. The Cerro Prieto plant accounts for close to the three quarters of total installed capacity in Mexico [69]. Due to the high investment needed for geothermal exploration, the potential of this RES in Mexico has not been fully evaluated. Considering recent estimates of the geothermal electric potential in Mexico, it is possible to conclude that it can be defined as 2310 MW from high- and intermediate-temperature hydrothermal resources and at least 5250 MW from high- and intermediate-temperature [73].

6. Biomass

There were 59 reported operating projects for co-generation and power supply in 2012 [67]. Biomass power has installed capacity of 548 MW in operation, 40 MW are from biogas and the rest from sugar cane bagasse biomass (Table 14). A potential production of bioenergy is estimated between 2635 and 3771 PJ/year in Mexico [74], where 77.9% would come from solid biomass such as *Eucalyptus* plantations, agroindustrial waste and crop residues, 20.1% from liquid bioenergetics (from sugarcane, *Jatropha curcas* and palm oil) and 2% from biogas (from municipal solid waste and cattle manure) [75]. It is important to point out that these estimations were based on suitable lands for each plantation and excluded those (a) used for agriculture, (b) covered by forests, jungles and other natural hedges, (c) belong to conservation areas and (d) non arable because they have a slope higher than 4–12%.

Mexico is the third largest country in Latin America and the Caribbean in terms of the cropland area, following Brazil and Argentina [76]. In 2007, the cultivated area was 21.7 million ha with an agricultural production of 270 million tons. There are crops widely cultivated, maize represents 40% of the total cultivated area, whereas sorghum, beans, oats, sugarcane, wheat and barley occupied almost 30% [77]. The residual biomass generated from these crops currently has diverse uses including animal feed and bedding, mulch, burning to produce energy and finally compost. The biomass utilization for obtaining energy is an attractive option for the rural sector due to its multiple potential social benefits [78]. In this way, Mexico would become a central focus of attention for the production of biofuels, a field that is still in the early stages of exploration. Before promoting biofuel production, it is necessary to first evaluate the natural potential of biomass as a starting point for strategic planning, to ensure a stable food supply and appropriate environmental protection standards.

Research investment in bioenergy in Mexico has been increasing during the last years (Fig. 14). The trend in the number of projects can be divided in two sections. The period 2004–2007 showed a reduced number of approved projects, from 23 to 64. However, the period 2008–2011 started with a high number of projects for a total of 134 projects in 2008 and a stable trend of 125 projects per year thereafter. The summation of each year's approved budget during this period was 78.3 million USD with an increasing trend with the exception of year 2007. The average approved budget per project increased from 17.9 to 261.1 thousand dollars from 2004 to 2011 [79]. Unfortunately, it was not possible to find information regarding the research investment grade for the rest of the renewable energy sources.

7. Renewable energy expected generation, barriers and solutions

Even though Mexico has a high potential of RES development, only a low percentage of this energy has been used (i.e. 1.7% and

Table 14
Installed biomass power capacity [67].

	Status	Installed capacity (MW)	Location
Biomass	In operation	508.0	Campeche, Chiapas, Colima, Jalisco, Michoacan, Morelos, Nayarit, Oaxaca, Puebla and others
	Under construction	88.0	Chiapas, Jalisco, Nayarit, Oaxaca and Veracruz
Biogas	In operation	40.0	Aguascalientes, Chihuahua, Mexico State, Nuevo Leon, Queretaro
	Under construction	5.0	Guanajuato, Jalisco
Total		641.0	

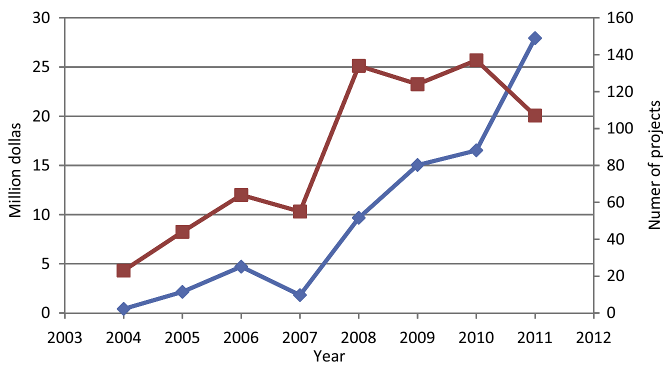


Fig. 14. Number of projects (squares) and budget (circles) per year in biomass energy in Mexico [75].

2.3% in wind and geothermal power). Therefore, there are huge investment opportunities to improve the use of RES, but also there are some barriers that prevent its expansion in Mexico:

A) Energy strategy: it is based on methodologies that evaluate the feasibility of RES in short terms. The lack of valorization of the use of renewable energies (stability in energy prices in long-term and energy security) and the important oil resources of the country, mean that policies and energy prospective are based on fossil fuels reserves.
B) Policies: the fact that public institutions, which provide electric energy to the country, have to consume the cheapest source by law (fossil fuels in this case), leads to the non-promotion of RES. That is why economic and fiscal incentives should be considered. Generation of more financial mechanisms to make RES competitive against conventional sources is also required.
C) Technology: although potential of most RES are known, some others have not been considered such as low-enthalpy geothermal energy or wave power. Investment in exploration of RES is also needed, specifically in the case of geothermal power.
D) Incentives: In order to encourage the private sector participation in power generation from renewable sources, institutions like the Energy Regulatory Commission (CREE), the Federal Electricity Commission (CFE) and the Ministry of Energy (SENER) offer the following incentives:
   - Energy bank: Enables producers to accumulate energy surpluses under the self-supply scheme to be used in the future or sold to CFE at the end of the year (compensation mechanism).
   - Preferential Rate of Energy Transmissions: Savings up to 65% in transmission services fee for renewable energy of efficient co-generation in comparison to the cost of transmitting conventional energy.
   - Net metering: It applies to small and medium scale projects (up to 10 KW for residential use, and 30 KW for businesses and up to 500 KW for projects). It compensates the cost of used power with the one contributed to the national network.

Table 15
Renewable energy power generation permits by scheme [69].

Power generation schemes	Permits	Capacity (MW)	Share in renewable energy installed capacity (%)
Self-supply	80	3224	77.1
Independent power producer	5	511	12.2
Small power producer	7	80	1.9
Co-generation	32	364	8.7
Total	124	4179	100.0

Table 16
Expected additional power generation capacity under Self-supply schemes (2010–2025) [69].

Energy	Self-supply (MW)	Share (%)
Wind	8264	84.6
Solar	601	6.1
Hydro	575	5.9
Biomass	324	3.3
Total	9764	100.0

At the end of 2012, there were 124 renewable energy power generation permits to produce 4179 MW under different schemes. These generation schemes considered self-supply, independent power producer, small power producer, co-generation. Self-supply had the highest installed capacity, 77.1% producing 3224 MW, the full scheme is shown in Table 15. Wind energy had most of the power generation permits (76.5%) followed by biomass (15.3%), hydropower (7.4%) and solar (0.8%) [69]. The expected additional power generation capacity under self-supply schemes for the 2025 included wind, solar, hydro and biomass sources; the highest producer as source expected is the wind with 8264 MW corresponding to 84.6% of production (Table 16) [69].

In order to overcome these barriers a series of suggestions have been proposed:

A) Adopt a general national plan for renewable energy in Mexico by explicit establishment of RES participation in the country's energy production (for each technology). Define the internal mechanisms to guarantee these goals according to the needs and resources available in the region of the country and potential technology to be used in this area.
B) The definition of financial schemes that help renewable energy small producers by economical and/or fiscal incentives.
C) Standardization and simplification of procedures for contracts of interconnection to the electrical grid which make an easier starting-up of new projects.
D) Investment in exploration and perforation for geothermal power.
E) Promotion of educational, research and development programs with founding from public-private collaboration.

8. Conclusions

In this paper a review of the research, use and potential of renewable energy sources in Mexico is presented, specifically, those related to hydropower, wind energy, solar energy, geothermal energy and bioenergy. Mexico ranks 9th in the world in crude oil reserves and 4th in natural gas reserves in America. The publicly owned company PEMEX is in charge of the exploration, distribution and commercialization of those resources. Mexico ranks 16th worldwide in power generation and the Federal Electric Commission (CFE) is the 6th largest power company in the world. Even though Mexico has relatively high crude oil reserves, the import of gasoline, diesel and jet fuel are still increasing due to the high demand of these fuels and limitations of refining facilities. By 2011, Mexico produced 219.5 Mtoe. Of this total an estimated 6.98% came from renewable sources where bioenergy and geothermal power had the highest impact. Power generation from renewable energy sources in Mexico is regarded to be low. About 16% of power generated came from this sources and its contribution has remained stagnant during the last decade. Research publications during the last 30 years (1982–2012) have been led by Universidad Nacional Autonoma de Mexico in hydropower, wind, solar and biomass energy and by Instituto de Investigaciones Electricas in geothermal energy. Researches have focused mainly in biomass and less in hydropower or wind energy which started the latest, 1988 and 1994 respectively. Regarding power generation in Mexico, hydropower has the highest installed capacity (11,603 MW), however Mexico is ranked 4th in geothermal power generation worldwide (958 MW). Although current power generation from solar technologies is low, it has a high potential because Mexico is among the top five most attractive countries in the world to invest in this renewable source. Wind energy is also an attractive RES with high potential concentrated mainly in the state of Oaxaca. Nonetheless, biomass energy has the highest potential for energy production, 2635 and 3771 PJ/year. On the other hand, the Law on the Use of Renewable Energy Sources has already been approved, but there still exist some barriers that do not allow RES technologies to exploit their potential. Thus, efforts should be addressed to avoid having an energy road map based on fossil fuels.

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References

[1] Group B. BP Statistical Review of World Energy June 2011. 2011.
[2] Demirbas A. Recent advances in biomass conversion technologies. Energy Edu Sci Technol 2000;6:19–40.
[3] Valdez-Vazquez I, Acevedo-Benítez JA, Hernández-Santiago C. Distribution and potential of bioenergy resources from agricultural activities in Mexico. Renew Sustain Energy Rev 2010;14:2147–53.
[4] Group B. BP Statistical Review of World Energy June 2012. 2012.
[5] Manzano-Agugliaro F. Use of bovine manure for ex situ bioremediation of diesel contaminated soils in Mexico. ITEA 2010.
[6] Manzano-Agugliaro F, Sanchez-Muros MJ, Barroso FG, Martínez-Sánchez A, Rojo S, Pérez-Bañón C. Insects for biodiesel production. Renew Sustain Energy Rev 2012;16:3744–53.
[7] Kalogirou S. Solar thermal collectors and applications. Progress Energy Combust Sci 2004;30:231–95.
[8] Hernandez-Escobedo Q, Manzano-Agugliaro F, Gazquez-Parra JA, Zapata-Sierra A. Is the wind a periodical phenomenon? The case of Mexico Renew Sustain Energy Rev 2011;15:721–8.
[9] Baños R, Manzano-Agugliaro F, Montoya FG, Gil C, Alcayde A, Gómez J. Optimization methods applied to renewable and sustainable energy: a review. Renew Sustain Energy Rev 2011;15:1753–66.
[10] Charters WW. Developing markets for renewable energy technologies. Renew Energy 2001;22:217–22.
[11] Dincer I. Environmental impacts of energy. Energy Policy 1999;27:845–54.
[12] Fridleifsson IB. Geothermal energy for the benefit of the people. Renew Sustain Energy Rev 2001;5:299–312.
[13] Network R. Renewables 2013-Global Status Report 2013. 2013.
[14] European Comission. Eurostat 〈http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/〉 2013.
[15] SENER. National Energy Balance 2011 2011.
[16] Islas J, Manzini F, Masera O. A prospective study of bioenergy use in Mexico. Energy 2007;32:2306–20.
[17] OECD. OECD Factbook 2013: Economic, Environmental and Social Statistics. 2013.
[18] Esen M, Yuksel T. Experimental evaluation of using various renewable energy sources for heating a greenhouse. Energy Build 2013;65:340–51.
[19] Esen M, Esen H. Experimental investigation of a two-phase closed thermosyphon solar water heater. Solar Energy 2005;79:459–68.
[20] Esen M. Thermal performance of a solar-aided latent heat store used for space heating by heat pump. Solar Energy 2000;69:15–25.
[21] Esen H, Inalli M, Esen M. Numerical and experimental analysis of a horizontal ground-coupled heat pump system. Build Environ 2007;42:1126–34.
[22] Balbay A, Esen M. Experimental investigation of using ground source heat pump system for snow melting on pavements and bridge decks. Sci Res Essays 2010;5:3955–66.
[23] Ozgen F, Esen M, Esen H. Experimental investigation of thermal performance of a double-flow solar air heater having aluminium cans. Renew Energy 2009;34:2391–8.
[24] Esen H, Inalli M, Esen M. Technoeconomic appraisal of a ground source heat pump system for a heating season in eastern Turkey. Energy Convers Manag 2006;47:1281–97.
[25] IRENA. Renewable energy country profile:Mexico. 2012.
[26] INEGI. Geographic references and territorial expansion of Mexico. 2013.
[27] Merrill T., Mirró R. Mexico: A country study 1997.
[28] CONAGUA. Water statistics in Mexico 2008. Mexico: 2009.
[29] CONAGUA. Weather in Mexico 2010.
[30] CONAGUA. Water statistics in Mexico 2011. Mexico: 2011.
[31] INEGI. Instituto Nacional de Estadistica y Geografia 2010.
[32] UNdata. Country profile Mexico 〈http://data.un.org/CountryProfile.aspx?crName=MEXICO〉 2013.
[33] SENER. Energy Sector Programme 2001–2006. 2001.
[34] SENER. Electricity Sector Prospective 2003–2012 2003.
[35] SENER. Energy and Environment Towards Sustainable Development. 2003.
[36] EIA. Country profile: Mexico. 2012.
[37] SENER. Oil Prospective 2012-–2026. 2012.
[38] CFE. Projects and Investment Program in the Electric Sector 2008–2017. 2008.
[39] OLADE. Energy and Sustainable Development in Latin America and the Caribbean: Guidelines for the formulation of energy policies. 2000.
[40] Islas J, Jerónimo U. The financing of the Mexican electrical sector. Energy Policy 2001;29:965–73.
[41] Janet Ruiz-Mendoza B, Sheinbaum-Pardo C. Electricity sector reforms in four Latin-American countries and their impact on carbon dioxide emissions and renewable energy. Energy Policy 2010;38:6755–66.
[42] Republic G of the. Energy Reform 2013:1–24.
[43] RECIPE. Mexican country study□: Part B – Energy and policy. 2005.
[44] Federal PE. National Strategic Plan for Development 2007–2012. n.d.
[45] UNDP. United Nations Development Programme Republic of Mexico. 2009.
[46] Alatorre C. Renewable Energies for Sustainable Development in Mexico. 2009.
[47] REEP. Sustainalbe energy policy initiative for Latin Amertrica and the Caribbean report. 2007.
[48] Network R. Renewables interactive map country profile: Mexico 2013.
[49] Camara de Diputados. Law for the use of renewable energy and finance of the energy transition. Diario Oficial De La Federación 2008:1–12.
[50] SENER. Anhydrous Ethanol Program Introduction 2011.
[51] Manzano-Agugliaro F, Alcayde A, Montoya FG, Zapata-Sierra A, Gil C. Scientific production of renewable energies worldwide: an overview. Renew Sustain Energy Rev 2013;18:134–43.
[52] Yin M-S. 41Fifteen years of grey system theory research: a historical review and bibliometric analysis. Expert Syst Appl 2013;40:2767–75.
[53] Zhi W, Ji G. Constructed wetlands, 1991–2011: a review of research development, current trends, and future directions. Sci Total Environ 2012;441:19–27.
[54] Ho Y-S. Top-cited articles in chemical engineering in science citation index expanded: a bibliometric analysis. Chin J Chem Eng 2012;20:478–88.
[55] Shi S, Yue C, Wang L, Sun X, Wang Q. A bibliometric analysis of anaerobic digestion for butanol production research trends. Procedia Environ Sci 2012;16:152–8.
[56] Wan T-J, Shen S-M, Bandyopadhyay A, Shu C-M. Bibliometric analysis of carbon dioxide reduction research trends during 1999–2009. Sep Purif Technol 2012;94:87–91.
[57] Pillania RK. Innovation research in India: a multidisciplinary literature review. Technol Forecast Soc Change 2012;79:716–20.
[58] Romo-Fernández LM, Guerrero-Bote VP, Moya-Anegón F. World scientific production on renewable energy, sustainability and the environment. Energy Sustain Dev 2012;16:500–8.
[59] Chang Y-W, Cheng T-W. Characteristics and trends of research articles authored by researchers affiliated with institute of chemical engineering in Taiwan. J Taiwan Inst Chem Eng 2012;43:331–8.
[60] Cruz VMV, Dierig DA. Trends in literature on new oilseed crops and related species: seeking evidence of increasing or waning interest. Ind Crops Prod 2012;37:141–8.

[61] Castro e Silva M, Teixeira AAC. A bibliometric account of the evolution of EE in the last two decades. Ecol Econ 2011;70:849–62.
[62] EPRI. Australian Electricity Generation Technology Costs-Reference Case 2010. 2010.
[63] Sheinbaum C, Ruiz BJ, Ozawa L. Energy consumption and related CO_2 emissions in five Latin American countries: changes from 1990 to 2006 and perspectives. Energy 2011;36:3629–38.
[64] CRE. Reports of the electricity sector ⟨http://www.cre.gob.mx/articulo.aspx?id=428⟩ 2013.
[65] SENER. Renewable energies in Mexico 2002.
[66] EPIA. Unlocking the sunbelt potential of photovoltaics. 2010.
[67] PROMEXICO. Renewable energy, Business Intelligence Unit. 2012.
[68] IIE. Geographic information system for renewable energies ⟨http://sag01.iie.org.mx/evaluarer/welcomeSIGER.html⟩ 2010.
[69] PROMEXICO. Self-supply in Renewable Power. Mexico: 2012.
[70] CONCAMIN. Private sector perspective in reference to energy management. 2012.
[71] AMDEE. Wind energy status in Mexico ⟨http://amdee.org/Recursos/Wind_Energy_Status_in_Mexico⟩ 2010.
[72] Asociacion Geotermica Mexicana. Geothermal Resources ⟨http://www.geotermia.org.mx/geotermia/?page_id=688⟩ 2013.
[73] Gutiérrez-negrín LCA. Update of the geothermal electric potential in Mexico. GRC Trans 2012;36:671–8.
[74] SENER. Introduction to Bioenergetics Program. 2010.
[75] REMBIO. Bioenergy in Mexico, current situation and outlook. 2011.
[76] CEPAL. Statistical yearbook for Latin America and the Caribbean, 2007 2008.
[77] SAGARPA. Food and Fisheries Information Service 2008.
[78] Demirbas A. Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. Energy Convers Manag 2008;49:2106–16.
[79] Riegelhaupt E, Cecotti L, Gutiérrez JP. Inventory Res, Dev Transfer Technol Bioenergy 2012.